(12) UK Patent Application (19) GB (11) 2 091 417 A

(21) Application No **8137954**
(22) Date of filing **16 Dec 1981**
(30) Priority data
(31) **8101533**
(32) **19 Jan 1981**
(33) **United Kingdom (GB)**
(43) Application published
28 Jul 1982
(51) **INT CL³**
G01N 23/08
(52) Domestic classification
G1A A4 C13 C2 C4 C6 C7 D10 D12 D3 G13 G16 G17 G1 G2 G5 G7 P10 P13 P1 R2 R7 S10 S12 S3 T15 T20 T3 T8
(56) Documents cited
GB 1560943
GB 1551835
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GB 1410823
GB 1403201
GB 1332370
GB 1017595
(58) Field of search
G1A
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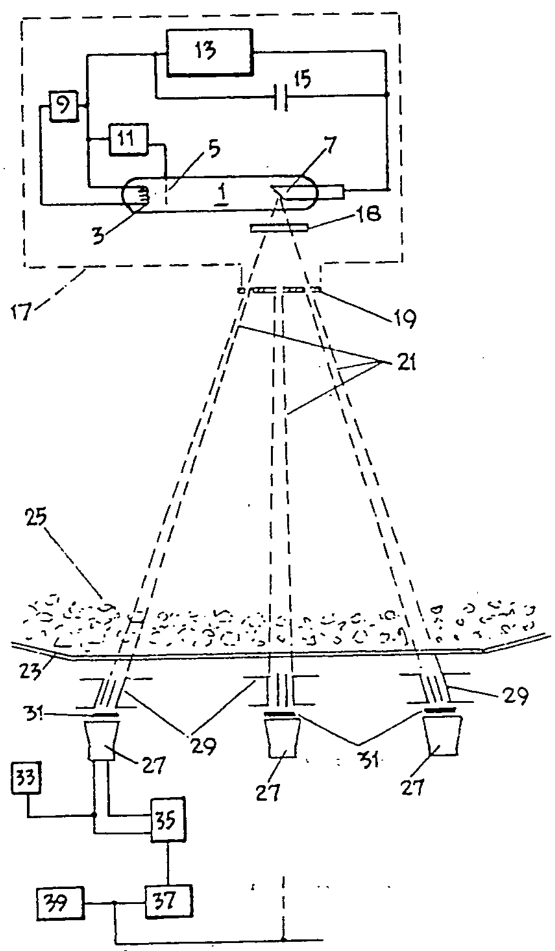
(54) Apparatus for examining materials

(57) An apparatus for determining the composition of a mixture of materials 25 (such as stone and coal) travelling on a conveyor belt 23 comprises an x-ray tube 1 arranged to produce a succession of pulses, the spectral composition of each of which varies with time in a predetermined manner, and a plurality of current mode radiation detectors 27 arranged to receive radiation from the tube after passage through the material to be examined.

According to a second aspect the apparatus comprises two x-ray tubes which alternately produce pulses of a different spectral composition, at least one current mode radiation detector receiving radiation from of the tubes after passage through the material to be examined.

As the attenuation of x-rays by a mass of material depends upon the spectral composition of the x-rays as well as the mass and composition of the material, the form of the signal derived from the detector or detectors gives information about the composition of the mixture of materials.

FIG.1.



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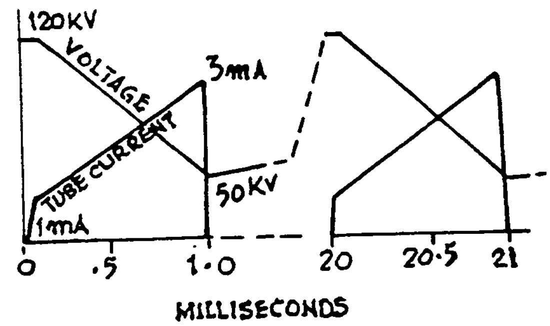

FIG.2.

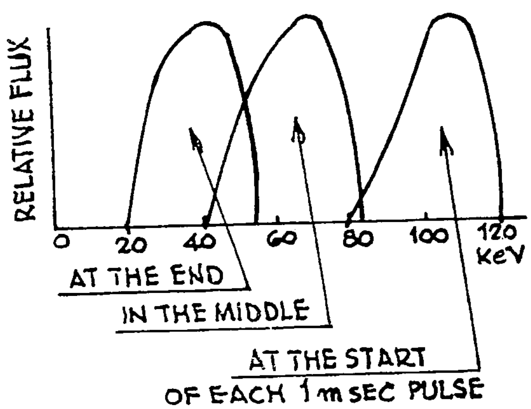

FIG.3.

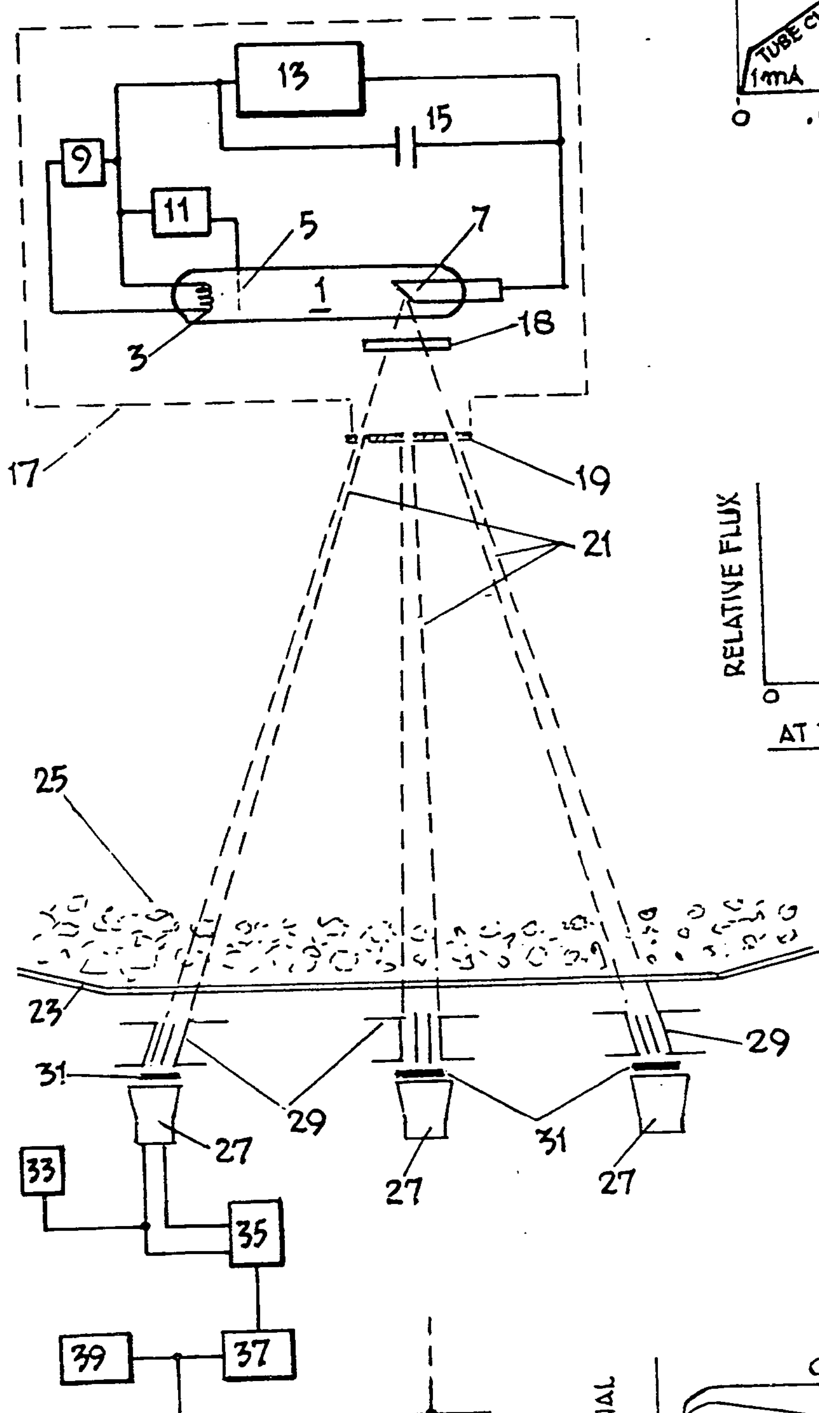

FIG.1.

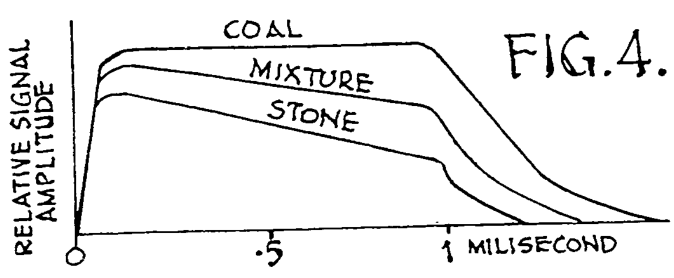

FIG.4.

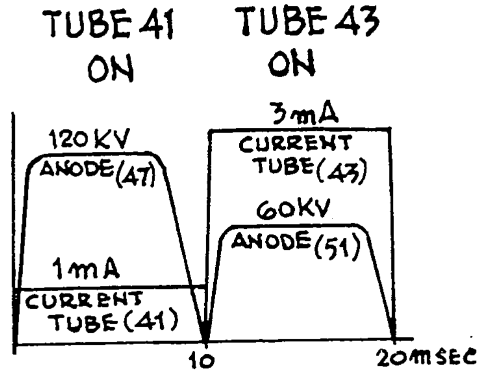

FIG. 6.

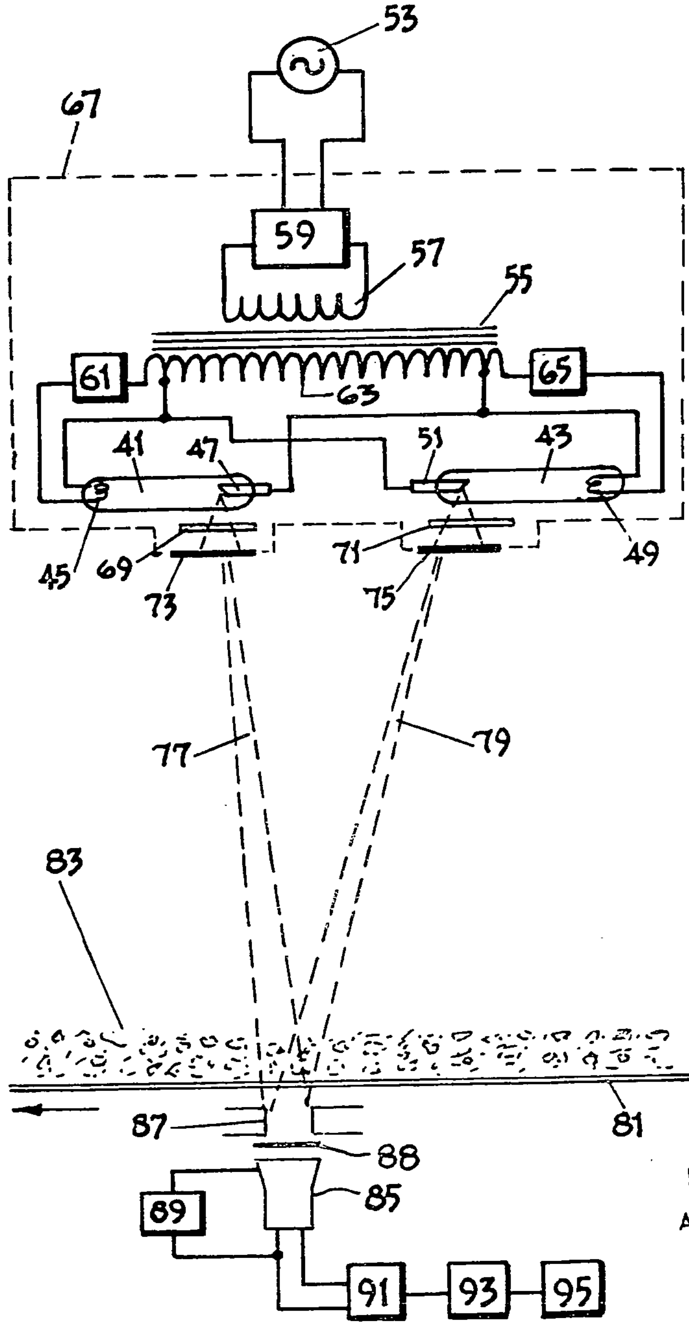

FIG. 5.

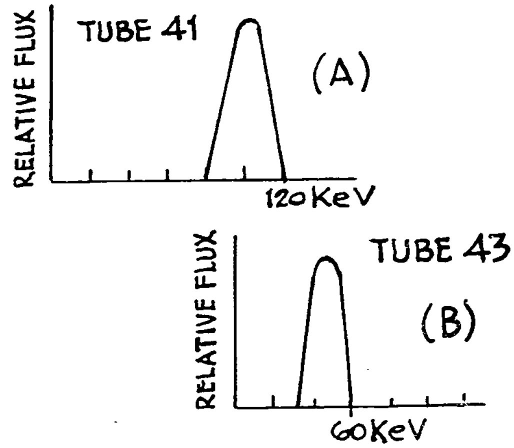

FIG. 7.

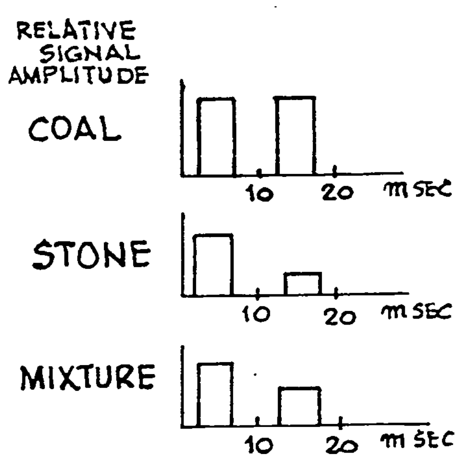

FIG. 8.

SPECIFICATION

Apparatus for examining materials

This invention relates to apparatus for examining materials.

More particularly the invention relates to such apparatus suitable for examining material travelling on a conveyor belt or the like.

Such apparatus finds application for example in mining operations for determining the amounts of wanted and unwanted materials, e.g. coal and stone, in the mined material.

In a known form of such apparatus the material to be examined is arranged to interrupt a beam of radiation directed onto a radiation detector, and the nature of the material is determined by monitoring the radiation received by the detector, i.e. the degree of attenuation of the radiation by the material interrupting the beam.

To simplify the extraction of the information required it is usual for the radiation to be derived from an essentially monomchromatic source, e.g. isotope originated gamma rays, and to use radiation detectors which can be arranged to respond only to received radiation of a predetermined energy e.g. so as to respond only to uncollided flux arriving at the detector. This arrangement suffers the drawback however of expense in that isotope originated gamma rays are limited in intensity, and consequently expensive detectors such as scintillation detectors which operate in a counting mode must be utilised. Additionally isotope sources tend to create a radiation hazard, particularly in underground environments such as those encountered in mining operations, since there is no way in which they can be "switched off".

It is an object of the present invention to provide a cheap apparatus for examining materials, using non-monochromatic radiation sources which can be made to be intrinsically safe e.g. x-ray tubes, and which produce radiation which is intense enough to be detected by cheap detectors working in the current mode e.g. a phosphor screen coupled with a photo-multiplier tube, radiation incident on the phosphor screen causing the emission of light by the screen which is measured by the photo-multiplier tube.

According to one aspect of the invention an apparatus for use in examining materials comprises: a radiation source; a current mode radiation detector arranged to receive radiation from the source after passage through the material to be examined; and means for operating the source so that a succession of pulses is produced, the spectral composition of each of which varies with time in predetermined manner.

According to a second aspect of the invention an apparatus for use in examining materials comprises: an plurality of radiation sources; a current mode radiation detector arranged to receive radiation from each of the sources after passage through the material to be examined, and means for operating the sources so that a pulse of radiation is produced by each source in turn and each source produces pulses of a different spectral composition.

In an apparatus according to either aspect of the invention said source or sources are preferably x-ray tubes.

In this case the means of producing pulses of varying or different spectral composition is by control of the anode voltage of the x-ray tube or tubes. The intensities of the pulses are then preferably kept substantially constant, or equal in the case of the second aspect, by appropriate control of the x-ray tube current(s). This is suitably achieved by variation of the x-ray tube grid voltage(s) or filament current.

In use of an apparatus in accordance with the invention the change in the output of the detector, during a pulse with apparatus according to the first aspect, or between pulses produced by different sources in apparatus according to the second aspect, enables independent properties of the material, e.g. total mass and attenuation characteristics, to be determined from the detector output.

Two apparatuses in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings in which:-

Figure 1 is a block schematic diagram of an apparatus in accordance with the first aspect of the invention;

Figures 2, 3 and 4 are graphs illustrating the operation of the apparatus of Figure 1;

Figure 5 is a block schematic diagram of an apparatus in accordance with the second aspect of the invention; and

Figures 6, 7 and 8 are graphs illustrating the operation of the apparatus of Figure 5.

Referring to Figure 1, the first apparatus to be described comprises an x-ray tube 1 having a filament 3, a control grid 5 and an anode target 7. The filament 3 is supplied with current from a source 9 and the potential of the grid 5 with respect to the filament 3 is controlled by a voltage supply 11. The anode voltage is supplied by voltage multiplier stack 13 and an associated reservoir capacitor 15 is connected between the supply to the grid 11 and the anode 7. The tube 1 and its associated power supplies are housed in an enclosure 17, the multiplier capacitors being suitably constructed as an integral part of the stack and the stack suitably being built in spiral form around the x-ray tube.

The x-rays produced by the tube 1 in operation pass through a spectral filter 18 and leave the enclosure 17 via a collimator 19 which divides the rays into a plurality of distinct, collimated beams 21, three of which only are shown in Figure 1 for clarity.

The x-ray tube enclosure 17 is mounted over a conveyor belt 23 on which the material 25 to be examined is loaded, the belt 23 travelling in a direction perpendicular to the plane of Figure 1.

Below the conveyor belt, suitably spaced across its width, there are disposed a plurality of photo-multiplier detector tubes 27 each associated with

a respective collimator 29. Each of the beams 21 is directed so as to impinge on a phosphor screen 31 coupled with a respective one of the tubes 27 after traversing the material 25 on the conveyor belt 23 and the associated collimator 29.

Each of the tubes 27 is provided with a high voltage supply 33 and the output of each tube 27 is fed via a logarithmic compressor circuit 35 to a signal processing circuit 37 wherein certain parameters of the output of the compressor circuit 35 are extracted for processing in a central processor 39, as further explained below.

The x-ray tube supplies are operated so as to produce a regular train of x-ray pulses, the anode voltage being varied during each pulse so that the spectral composition of each pulse changes with time in a controlled manner. The tube current is also caused to vary during the pulse, so that the intensity of the emitted radiation remains substantially constant throughout the duration of the pulse, the tube current being controlled by means of the grid voltage since control by variation of the filament current is too slow.

Where the material on the conveyor is a mixture of coal and stone the pulses suitably occur at a rate of 50 per second (i.e. mains frequency) and have a duration of 1 millisecond. During each pulse the anode voltage decreases from 120 kilovolts to 50 kilovolts and the tube current increases from 1 milliamp to 3 milliamps, as illustrated in Figure 2. The spectral composition of each 1 millisecond pulse, after filtering, consequently varies with time as illustrated in Figure 3 from which it will be seen that the hardness of the x-rays produced during a pulse decreases while the intensity remains roughly constant. The choice of spectral filter 18 will be determined by the necessity to produce x-rays which at any given time within the pulse have a ressonably limited spectral spread extending to high energy maximum so that the signal output from the detector can be interpreted as explained hereafter, whilst still maintaining an easily measurable x-ray flux. Due to the fact that the attenuation of x-rays by a mass of material depends upon the spectral composition of the x-rays as well as on the mass and composition of the material, the form of the signal produced at the output of the compressor circuit 35 during each pulse depends on the mass and the composition of (i.e. the relative proportions of coal and stone in) the material 25 on the conveyor belt 23. Thus, as illustrated in Figure 4, for one particular mass of coal on the belt the output of circuit 35 may be arranged to be substantially constant. For an equal mass of a stone/coal mixture an output which decreases throughout the pulse will then be obtained, the rate of decrease being a maximum when the mixture contains no coal, i.e. consists entirely of stone. For other masses of mateiral, a different family of curves relating the output of the compressor circuit 23 and the composition of the mixture on the conveyor belt is obtained. Thus by inspection of the form of each output pulses of the compressor circuit 35, the mass and composition of the material on the belt may be continuously monitored.

To this end the circuit 37 may thus be arranged to produce outputs representing, for example, the peak value and slope of each output pulse, the peak value and area under each pulse, the amplitude of the pulse at two known time spaced positions, or the areas under the pulse during two selected periods near the leading and trailing edges of each pulse. Such outputs are then utilised by the central processor, in conjunction with stored information relating pulse shape to material mass and composition, to calculate the mass and composition of the material currently interrupting the x-ray beams.

Referring now to Figure 5, the second apparatus to be described comprises two x-ray tubes 41 and 43, the tube 41 having a filament 45 and an anode target 47 and the tube 43 having a filament 49 and an anode target 51.

The filament and anode supplies for the tubes 41 and 43 are derived from a mains a.c. supply 53 by way of a transformer 55 whose primary winding 57 is connected to the supply 53 by way of a control circuit 59. The filament supply for the tube 41 is derived by way of a filament current control circuit 61 from across a small portion of the transformer secondary winding 63 at one end of the winding, and the filament supply for the tube 43 is similarly derived by way of a filament current control circuit 65 from across a small portion of the transformer secondary winding 63 at the other endof the winding. The anodes 49 and 51 of the tubes 41 and 43 are connected to opposite ends of the part of the secondary winding 63 between the end portions used for the filament supplies so that the tubes 41 and 43 are energised during alternate half cycles of the mains supply.

The tubes 41 and 43 together with the transformer 55 and the associated control circuits are housed within an enclosure 67.

The x-rays produced by the tubes 41 and 43 in operation pass through respective spectral filters 69 and 71 and leave the enclosure 67 via respective collimators 73 and 75 to form beams 77 and 79.

The x-ray tube enclosure 67 is mounted over a conveyor belt 81 on which the material 83 to be examined is loaded, the belt 81 travelling in the direction of the arrow in Figure 5.

Below the conveyor belt 81 there is disposed a photomultiplier tube 85 associated with a collimator 87, the beams 77 and 79 both being directed so as to impinge on the phosphor screen 88 coupled to the photo-multiplier tube 85 after traversing the material 83 on the conveyor belt 81 and the collimator 87.

The photo-multiplier tube 85 is provided with an high voltage supply 89 and the output of the tube 85 is fed via a logarithmic compressor circuit 91 to a gating circuit 93 whose output is fed to a central processor 95.

Normally, further phosphor screen photo-

multiplier combinations will be provided at spaced positions across the width of the belt 81, the signals derived from each detector tube being fed to the central processor 95.

In operation the circuit 59 shapes the waveform of the transformer primary voltage and the circuits 61 and 65 control the filament currents of the tubes 41 and 43 so that the spectral composition of the x-ray pulses produce by x-ray tube 41 centre round a higher energy than the pulses produced by x-ray tube 43 whilst their intensities are substantially the same.

In particular the current in the primary winding of the transformer 55 is shaped by, for example, a diode control circuit, so that the voltage pulses supplied to either anode 47, 51 have flat topped shapes, such as seen in Figure 6. Where the material on the conveyor is a mixture of coal and stone the anode voltages of the two tubes 41 and 43 are suitably of peak values 120 kilovolts, and 60 kilovolts respectively, and their currents 1 milliamp and 3 milliamps respectively.

The spectral composition of the beams produced by the tubes 41 and 43, after filtering, are consequently of the form indicated in Figures 7A and 7B respectively, i.e. of similar spectral width and peak intensity, but having different peak hardnesses of 120 kilo-electronvolts and 60 kilo-electronvolts respectively. It will be appreciated in this connection that each of the filters 69 and 71 is tuned to the peak hardness of the output of its associated x-ray tube 41 or 43 and as in the first apparatus the choice of the filters 69 and 71 is determined by the necessity to obtain spectrally separated spectral distribution whilst still maintaining an easily measurable x-ray flux.

The circuits 91 and 93 are arranged to produce for each x-ray pulse received by the detector tube 85, an output pulse of square waveform and an amplitude dependent on the total radiation received by the tube 85 during the central portion of corresponding x-ray pulse. Thus the gating circuit 93 is effective to remove the effects of radiation received in the vicinity of the leading and trailing edges of each x-ray pulse to give an output which approaches that which would be given by dc operation of either tube.

Due to the fact that the attenuation of x-rays by coal varies with x-ray hardness differently from the corresponding variation of attenuation by stone, the mass of and the relative proportions of coal and stone in the material 83 may be deduced from the amplitudes of consecutive pairs of pulses appearing at the output of circuit 93 in response to x-ray pulses produced by the tubes 41 and 43 respectively.

For example, as illustrated in Figure 8, for one particular mass of coal on the belt the amplitude of the pulse appearing at the output of circuit 93 in response to an x-ray pulse produced by tube 41 may be arranged to be the same as the amplitude of the pulse appearing at the output of circuit 93 in response to an x-ray pulse produced by tube 43. For an equal mass of a stone/coal mixture the pulse produced in response to x-rays from tube 43 will then be smaller than the pulse produced to x-rays from tube 41, the difference in amplitudes being a maximum when no coal is present, as illustrated in Figure 8.

For different masses of material 83, pairs of pulses of different relative and absolute values are obtained according to the mass and composition of the material. Thus, by inspection of the amplitudes of pairs of consecutive output pulses of the circuit 93, and in conjunction with stored information relating amplitudes to material mass and composition, the mass and composition of the material currently interrupting the x-ray beams can be continuously monitored by the central processor 95.

It will be appreciated that the x-ray tubes must be positioned so that the same part of the material on the belt 81 is examined during consecutive x-ray pulses produced by the tube 43 and 41.

In the apparatuses described the collimators 29 and 87 serve to reduce the proportion of collided flux reaching the detector tubes 27 and 85.

To improve the efficiency of x-ray detection the detectors 27 and 85 are suitably provided with phosphor screens matched in shape and size to the cross-sections of the x-ray beams. The light produced by such screens may then be coupled to photomultiplier tubes of conventional form via light guides e.g. optical fibres.

To compensate for undesired fluctuations of x-ray intensity, the apparatuses of Figures 1 and 5 may be provided with air path standardising channels (not shown) as is frequently done in x-ray radiography apparatus. Similarly, means for compensating for sensitivity changes of the photomultiplier detector tubes and associated circuits may be provided, for example, by intermitantly injecting visible light through a fibre optic waveguide to each photomultiplier tube. System calibrating channels loaded with samples of stone or coal may also be provided.

CLAIMS

1. An apparatus for use in examining material comprising:- a radiation source; a current mode radiation detector arranged to receive radiation from the source after passage through the material to be examined; and means for operating the source so that a succession of pulses is produced, the spectral composition of each of which varies with time in predetermined manner.

2. An apparatus according to Claim 1 in which said radiation source comprises an x-ray tube and said operating means varies the anode voltage of the x-ray tube during each said pulse.

3. An apparatus according to Claim 2 in which said operating means maintains the intensities of the pulses substantially constant.

4. An apparatus according to Claim 3 in which the intensities of the pulses are controlled by variation of the x-ray tube current.

5. An apparatus according to Claim 4 in which said x-ray tube current is controlled by the x-ray tube grid voltage.

6. An apparatus according to Claim 5 in which

the x-ray tube current is partly derived from a capacitor.

7. An apparatus according to any one of the preceding claims adapted for energisation from an a.c. supply.

8. An apparatus for use in examining materials comprising: a plurality of radiation sources; a current mode radiation detector arranged to receive radiation from each of the sources after passage through the material to be examined, and means for operating the sources so that a pulse of radiation is produced by each source in turn, and each source produces pulses of a different spectral composition.

9. An apparatus according to Claim 8 in which said sources comprise x-ray tubes and said operating means operates each tube at a different anode voltage.

10. An apparatus according to Claim 9 in which said operating means maintains the intensities of said pulses substantially constant.

11. An apparatus according to Claim 10 in which the intensities of the pulses are controlled by variation of the x-ray tube filament currents.

12. An apparatus according to any one of Claims 9 to 11 adapted for energisation from an a.c. supply, the apparatus including two x-ray tubes which are energised during alternate half cycles of the supply.

13. An apparatus according to any one of Claims 9 to 12 in which the filament and anode supplies are derived from an a.c. supply by way of a transformer, the primary current of which is controlled so that the voltage pulses supplied to the anode have a flat topped shape.

14. An apparatus according to CLaim 13 in which said radiation detectors are connected to electrical circuitry effective to remove the effects of radiation received in the vicinity of the leading and trailing edges of each x-ray pulse.

15. An apparatus according to any of the preceding claims in which the or each radiation detector comprises a phosphor screen coupled to a photomultiplier tube.

16. An apparatus according to Claim 15 including fibre-optic waveguides to monitor detector sensitivities independent of x-rays.

17. An apparatus according to any one of the preceding claims including an air path standardising channel.

18. An apparatus according to any one of the preceding claims including systen calibrating channels loaded with samples of stone or coal.

19. An apparatus according to any one of the preceding claims wherein the or each radiation source is associated with a filter for spectrally shaping the radiation emitted by the source.

20. An apparatus substantially as hereinbefore described with reference to Figure 1 or Figure 5 of the accompanying drawings.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1982. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.